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Analysis of a topology control paradigm in WLAN/WPAN environments

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Abstract

The coordinated coexistence of WLANs and WPANs in a *dual-mode* network is a recently introduced idea and is expected to increase the overall *system performance* by allowing for the efficient cooperation of both WLANs and WPANs. *Topology control* (e.g., power control, smart antennas, and different frequency channels) needs to be employed to allow for the simultaneous operation of both modes. In this paper, different frequency channels that allow for *high data rates* within a *small transmission range* are considered in order to create multiple WPAN environments inside a WLAN cell. The latter environment requires the support of a second mode of operation which introduces additional *overhead* that may degrade the overall system performance. Certain conditions, under which system performance improvement is achievable, are established here. In particular, an analytical *mobility model* for WPAN environments is proposed and employed in the analytical studies. It is shown that the system may be effective when node *mobility* is low and the *traffic load* among nodes is high. The corresponding *upper* and *lower* bounds on mobility and traffic are also analytically derived. Simulation results for a variety of scenarios support the claims and expectations of the aforementioned analysis and demonstrate that performance improvement is possible when WLANs and WPANs coexist and cooperate in a network.

Keywords: Mobility model; WLAN; WPAN; Topology control

1. Introduction

The evolving *third generation* (3G) of telecommunication systems focuses on the individual users and their needs for increased data rates. However, with the advance of the Wireless Local Area Network (WLAN) technologies in the last years, the adoption of WLANs as last mile networks in 3G systems has started to gain ground [1,2]. As the demand for higher data rates increases due to the modern sophisticated applications, the central coordinator of a WLAN network (e.g., the Access Point depicted in Fig. 1a) becomes the obvious bottleneck node even when mobile terminals (MTs) that need to exchange large amounts of data between each other are located in the same cell (coverage area of the Access Point).

The idea of using a *second mode of operation* has been recognized as a promising technique in order to increase the capacity of a WLAN network [3–10]. In [9,10], the second mode of operation is employed in a different frequency, compared to the traditional WLAN one, allowing users, that want to exchange data locally, to operate in the network by applying high-rate, short-range communications and, at the same time, limit the *interference* imposed by the presence of other nodes in the WLAN cell. Fig. 1b depicts the case where MT A and MT B have switched to the second mode of operation in order to exchange data locally.

The coexistence of two modes of operation along with the two distinct types of network topologies (the large WLAN umbrella containing potentially several WPAN

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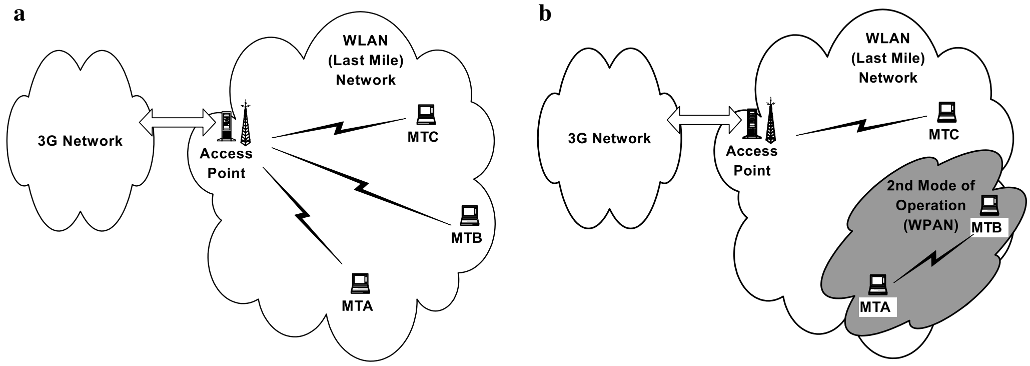

Fig. 1. Last mile network example. The Access Point of the WLAN is connected to the core 3G network. (a) First mode of operation; (b) support of a second mode of operation.

islands which are called *clusters*) requires the application of some type of *topology control*. In this paper, topology control may be defined as a node's capability of controlling the set of its neighbor nodes [11]. A node u is a neighbor node to another node v, if a direct transmission from node u to node v is possible. Power control and/or smart antennas may be used for topology control [12–20]. Power control can be applied to adapt the transmission power in accordance with the location of the receiver. Smart antennas may be employed in order for the nodes to be capable of adjusting transmission/reception angles. A third approach is to allow nodes to operate at different frequency channels [9].

Under any of the aforementioned approaches, the coordination of the second mode of operation within the WLAN framework is challenging. The performance of the resulting system depends on various factors such as: (a) the mobility of the nodes; (b) the load of the data traffic; (c) the availability of the bandwidth [9,11]. This work focuses on the first two factors assuming that the bandwidth provided by the second mode of operation is high compared to that under the customary first mode of operation (WLAN operation), as it is also discussed in Section 2. The design specification for the support of the second mode of operation using different frequency channels, presented in [10], is adopted here but it may be extended for any other approach used for topology control (smart antennas or power control). Under this specification, a second mode is established that supports high data rates for nodes close to each other that do not necessarily operate at the same frequency channel.

An essential component of the system design, presented in Section 2, is the *Neighborhood Discovery phase* (ND phase) that determines the set of neighbor nodes – with respect to the second mode of operation – of each node in the network. During the ND phase, all nodes are required to broadcast "hello" messages and consequently, additional *overhead* is introduced in the system. Two key modules, the *Neighborhood Discovery Indicator* (NDI) module and the *Centralized Clustering-Routing* (CCR) module, are responsible for determining the *time period* between two consecutive ND phases and the *set of nodes* that will operate in the second mode forming clusters, respectively. An analytically tractable model, capturing effectively the mobility behavior of the nodes inside a WPAN environment and taking also into consideration the wireless channel, is derived and studied in Section 3. This model is innovative and fairly realistic for personal area environments where users are expected to move close to the nodes that they want to communicate with. Analytical results leading to the derivation of the time period between consecutive ND phases that may be proved beneficial for the system are presented in Section 4. In Section 5, the overhead introduced for the support of the second mode of operation is considered in order to determine the conditions under which nodes creating clusters benefit from the second mode of operation. It is shown that the considered second mode of operation may be efficiently incorporated into the resulting system under certain mobility and traffic conditions, which are established in this work. Simulation results, presented in Section 6, support the claims and the expectations of the aforementioned analysis. The conclusions are drawn in Section 7.

The major contribution of this work is twofold: on the one hand, a novel mobility model that takes into account the wireless channel for the WPAN environment is introduced, while, on the other, performance aspects of the dual-mode system are analytically studied and demonstrated through simulations. It should be noted that the basis of our analysis is the system described in [9,10], the key aspects of which are discussed in Section 2.

2. System description

The design requirements for supporting a second mode of operation in a WLAN network using different frequency channels were first presented in [9]. The described system was based on HiperLAN/2 [21], but it could be easily extended for other WLAN systems (e.g., IEEE 802.11). According to the HiperLAN/2 standard, the Access Point (AP) is responsible for all operations in its 5 GHz cell. A second mode of operation at 60 GHz is possible, if certain new modules, described later in this section, are included in the standard HiperLAN/2 protocol stack [10]. Different